Landscape Characterization to Assess Impact and Magnitude of Roads on the Urban Spaces of Delhi, India

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Abstract

Quantification of landscape pattern and its transformation is crucial for assessment and monitoring of environmental consequences of urban infrastructure development. In the present study, geospatial tools and landscape metrics have been coalesced to quantify impacts of roads on spatial pattern of urbanization in Delhi using Quickbird (0.6m) dataset by varying grain size and across the transects 1 (Roads and urban class as individual entity) and 2 (roads and urban class treated as aggregate entity). Landscape metrics were computed along a 31 km long and 6 km wide transect (West to East direction) using standard and moving window analysis. The results of transect analysis showed that urbanization together with infrastructure development have resulted in increased patch density (PD), patch and landscape shape complexity (LSI), while a spectacular decrease in the largest and mean patch size (LPI) and landscape connectivity or increased fragmentation have been observed. The changes in landscape pattern along the transect have important ecological implications, and quantifying it at varied grain size, as illustrated in this paper, is an important first step to link patterns with processes in urban environs.

Key words: Urbanization, landscape metrics, patch, remote sensing, roads

1. Introduction

Urbanization and rapid infrastructure developments are considered key factors of land transformation profoundly influencing microclimatic conditions, green spaces and human life. Ecological consequences of urbanization and developmental plans are interesting and important to monitor and assess. Landscape analysis is one such attempt that can be used to quantify these. It further assists to understand concept of urban-rural gradient (McDonnell et al. 1997, Miller and Pillsbury 2008), which enhance variety of ecological issues in urban areas (Harshberger 1923). Still there exists a great gap in understanding these ecosystems (Collins et al. 2000, Wu 2000). Various methods such as gradient analysis (Godron and Forman 1983, McDonnell and Pickett, 1990) and landscape pattern metrics have been employed to understand the spatial pattern of urbanization with its ecological processes and thereby providing means to relate urban environment and people spatially and location of urbanization center with multiple indices (Alberti and Botsford 2000, Alberti 2001). Geographers and social scientist have carried out spatial pattern and urban dynamics of urban-rural areas with little or only superficial consideration of ecology in and around cities (Forrester 1969, Berry and Kasarda 1977, Butty and Longley 1994, Schneider and Woodcock 2008). By uncovering such characteristics of urban fragmentation along the gradient of land use zones, spatial distribution of urban fragmentation can be understood.

Rapid developmental activities in transportation sector due to increasing urban demand have resulted in alteration of
land use land cover (LULC) pattern. Construction of roads is one such activity that has brought important effects to landscape. Depending on the adjacency to nearby LULC the impacts of roads vary such as some are easily identifiable and some show effect with time. For example, impacts of forest roads such as dissecting the land, leading to habitat fragmentation, shrinkage, and attrition have been spatially viewed and quantified at several times (Reed et al. 1996), however, ecological impacts of roads in urban landscape have rarely been reported. The integrated urban ecosystems need new and integrative perspectives (Pickett et al. 1997, Grimm et al. 2000, Zipperer et al. 2000).

Over the year, the urban development of Delhi have been on the fringes and in radial pattern with reliance on road infrastructure. The development envisaged by previous plans were polynodal with hierarchy of Commercial Centers located on either ring or radial roads. The MRTS network, underpass, overpass, metro networking have brought connectivity thereby having impact on the existing structure of city and consequently its development. This changed scenario has provided opportunities for city restructuring and alterations in LULC pattern. The present study was taken up with multifold objectives. We aim to assess changes of road patches to urban landscape pattern and relationship between the two. It has been accomplished while analyzing landscape in transect where road patches merge with urban areas. In this paper, the theoretical basis and general structure of landscape pattern metrics and effect of grain size have been used to address impact of road development on urban landscape.

2. Study Area

Delhi lies between latitudinal parallels of 28°40' N and 28°67' N and longitudinal parallels of 77°14' E and 77°22' E and occupies northern region of India (216 meters above sea level). With an area of 1483 sq.km it corresponds to a typical patch of tropical region, completely engrossed with residential, commercial and urban centers. The region is undergoing rapid urban sprawl because of unprecedented developmental activities and population growth. A 31 km × 6 km study area located in central region traversing from West to East of Delhi is chosen in this case study (Figure. 1).

3. Material and Methods

The Quickbird images acquired on 2008-03-15 (pan sharpened-0.6m) were georeferenced using a polynomial approach. Five LULC classes were extracted using interactive approach of both visual and digital interpretation with the aid of ancillary data (e.g., pre-classified maps, topographic maps). Two transects were subset from imagery. Transect 1 comprises five LULC classes viz. open area, green spaces, urban area, roads and water body and Transect 2 contains four classes in which roads were merged with the urban area. The LULC raster was resampled to varying pixel size (1.2m, 3m, 5m, 15m, 30m and 60m) from the original data of 0.6m grain size using nearest neighborhood technique.

The derived resampled files were exported to GRID file format. Class properties file was prepared to set the run parameterization using Fragstats v.3.3. A series of landscape metrics at class and landscape level were calculated using 8-neighbors patch delineation rule. Standard and moving window analysis were performed each for Transect 1 and Transect 2. Landscape metrics at class and landscape level with variable pixel size were analyzed with regard to dynamic information of landscape and to determine the optimal grain size for impact analysis study of roads and characteristics of landscape dynamics.

4. Results and Discussion

The major LULC classes are open area, green spaces, urban area, roads and water body. The open area refers to agricultural fields, scrub, riverbed and vacant lands in and around the city. The green spaces are ridge forest, biodiversity part of city and all urban green spaces along roadsides and settlements. Because of high resolution data linear green spaces could be mapped very conveniently. Urban area refers to all settlements in and around city. No attempt has been taken to classify the type of settlement and define any part of the settlement as rural, which is very difficult in Delhi. Roads are linear feature in and around settlements. Roads were also mapped in open areas and green spaces. Visual interpretation
technique was used to delineate road network. River, canal network and small water bodies are classified as water. The overall accuracy of LULC interpretations exceeds 85% for all classes based on validation using the random points selected from original images.

Class area (CA) is a measure of landscape composition i.e. how much of landscape is composed of particular patch type. CA of transect 1 (Figure. 2a) shows that open areas composition is highest and rest follows the sequence as urban > vegetation > roads > water body. However in Transect 2 (Figure. 2b), when urban and roads are merged, CA is still higher for open areas but value of urban and road class area has increased which is not additive in nature. Rest classes does follows similar trend as in transect 1 such as urban + roads > vegetation > water body. Thus this shows that road and urban area when combined together exert a greater influence on landscape pattern and alters the landscape composition.

PLAND reveals the most important information about landscape composition because quantitatively different LULC types generally would have different landscape pattern attributes. The PLAND of open area is considerably higher followed by urban structures. Vegetation class is slightly lower in occupancy. Road though being a linear feature does show greater occupancy thus showing its impact in landscape composition. Percentage occupancy of land shows similar trend as class area.

PLAND of all class in Transect 1 decreased at varying grain size thus suggesting that grain size play a key role in determining composition of landscape classes (Figure. 3a). Up to 6m grain size, change in PLAND is quite significant but as the grain size increased from 6m to 15m, 30m and 60m, grain size does tend to show saturation and hence change in PLAND is not quite significant. This suggests that up to 6m resolution urban landscape composition at local scale can be evaluated for studying identified classes as at coarser resolution, PLAND value gradually saturates and hence is degree of differentiation reduces at coarser resolution datasets. The similar trend was observed in transect 2 (Figure. 3b). This is in concordance because width of roads in Delhi does not exceed more than 15m and streets are much

![Figure 2a. LULC and class area for Transect 1](image)

![Figure 2b. LULC and class area for Transect 2](image)

![Figure 3a. PLAND for Transect 1](image)

![Figure 3b. PLAND for Transect 2](image)
Narrower than this and thus coarser resolution datasets may fail to capture landscape pattern beyond 15m grain size.

The results from class level metric moving window analysis along transect are shown in Figure 4a and 4b. The diagram shows spatial changes of landscape pattern. On each diagram the horizontal axis represents rural-urban-rural gradient from West to East and vertical axis represents the metric value. The major reason behind the following interpretation is how the changes in landscape pattern are related to process of urbanization. This also identifies the impact of grain size and visualizing impact of road network on the adjacent features and landscape patterns (patch density primarily). The V shape curve indicates that metric having an inverted V-shape distribution is positively correlated to the degree of urbanization and others (representing V-shape distribution) are negatively correlated to degree of urbanization.

Patch Density (PD) is highest value in the urban core indicating a highly fragmented landscape and decreasing on both sides of the urban axis consisting of regions of suburban and rural areas. The central region being the city zone area, higher PD and hence higher fragmentation is obvious across all classes. Figure 4a and 4b show the trend of PD in both transects. The fragmentation in urban class is higher in transect 2 than that of 1 as road patches have been merged. This suggests that road developmental activities together with urbanization tend to have influence on landscape composition and structure and the developmental activities inappropriately planned would influence it to greater extent. Grain size also plays important role in determining the PD as it determines the maximum number of patches per unit area. An inverse relationship is observed between PD and grain size (Figure. 5a). The graph shows that PD tend to decrease across all classes as the grain size decreases from 1.2m to 3m, 6m, 15m, 30m respectively. However at coarser resolution PD of all classes are very low and differentiation of classes is not much significant. However in transect 2 the PD is comparatively higher for urban region thus exhibiting fragmentation characteristics even at coarser resolution (Figure. 5b). The graph also depicts sensitivity of roads to varying grain size and saturation being achieved beyond 15m. This is also attributed to small width of roads which could be picked up only because of unique spatial signature and only using spatial resolution less than 15 m.

Mean patch size (MPS) is lowest at urban core region indicating a fragmented landscape that is composed of many small patches. For the Western and Eastern half of the transect MPS increases gradually with distance from city center, indicating an increase in land parcel size. However MPS of urban class is comparatively higher in Transect 2 than 1 which illustrates road patches when merged with urban class tends to exert greater influence than urban and road class individually. Landscape Patches Index (LPI) showed monotonically increasing trend with increasing pixel/grain size indicating dominance value of class increases with increasing resolution. Moreover, LPI saturated beyond a resolution value of 30m and does not have appreciable
effect on landscape class. Thus LPI measures should be used carefully when comparing landscapes at varied grain size. Landscape Shape Index (LSI) showed a gradual declining trend. There are apparent effects to respond to variable grain sizes in class-level and landscape-level.

Perimeter-Area Fractal Dimension (PAFRAC) approaches 1 for shape with very simple perimeters such as squares and approaches 2 as the patch complexity increases. It’s an indicative of shape complexity across a range of spatial scales. PFRAC of all classes is considerably higher at resolution of 1.2m and it tends to decrease with increasing grain size (Figure 6a). Thus it suggests that at high-resolution shape complexity is much greater and this trend gradually diminishes as spatial scale varies from finer to coarser resolution. The increased complexity of merged urban and roads landscape in transect 2 suggests that it tends to have greater influence on urban landscape structure than roads and urban classes alone (Figure. 6b). Thus, road indeed tend to increase complexity of landscape which is identifiable at finer scale thus its developmental planning should be taken with greater concern and contemplation.

Clumpiness Index (CLUMPY) was calculated for determining the focal patch type disaggregation/aggregation and degree of disaggregation/ aggregation. CLUMPY equals -1 when maximally disaggregated, 0 distributed randomly, and approaches 1 as maximally aggregated. Among all classes in Transect 1 road patches showed maximum disaggregation and degree of disaggregation increased as resolution of grain size increased. This is quite evident with transect 2 study too. As the transect grain size increased road patches appear maximally disaggregated and the degree of disaggregation was highest among all class patch type. Water body showed highest aggregation at all grain sizes however the degree of association weakened at resolution greater than 30m. The aggregation index of class patch type followed the sequence as water body followed by vegetation, open, urban and road class patches (Figure.7 and 8).

However scale of disaggregation follows the reverse sequence. In the Transect 2 CLUMPY of merged Urban and road class is higher than the vegetation patch showing greater
aggregation measure than Transect 1 (Figure. 9a and 9b). Road tends to increase aggregation measure of urban area and hence tend to transform landscape pattern and processes.

Patch cohesion index (PCI) measures the physical connectedness of the corresponding patch type. In present analysis, PCI is highest for open areas and least for road thus typifying that open areas is maximum aggregated and road is least aggregated in its distribution and hence more physical connectivity among open areas than roads. The degree of PCI decreased with increasing grain size but changes were more evident in road class only. In Transect 2, degree of physical connectedness is still higher than Transect 1 (Figure. 10a and 10b). Merged urban and road classes show comparatively higher PCI than urban and road structures alone indicating more clumped or aggregation in its distribution, hence more physically connected.

The above interpretations conclude that selection of appropriate grain size is the first parameter to be established.
The appropriate range of grain for landscape indices of Delhi transect was 1.2m to 15m. The above results show that urbanization has resulted in dramatic structural changes of metropolitan landscape. For example, as urbanization progressed large and contiguous patches were broken up with an increasing number of patch types (LULC types) occurring in landscape. The density of patches of various types and thus PLAND composition increased exponentially. The overall LPT increased steadily mainly due to increasingly even proportions of dominant LULC types whereas geometric shapes of patches in landscape as a whole became more and more irregular. As a result, urbanization has brought about increased structural fragmentation and complexity of landscape in Delhi region. In present analysis most critical points occur within 1.2-15m which is width range of some landscape elements, such as roads, branches of rivers. When grain size increases over this range, these elements shrink to small patches or are masked by other dominating elements, thus inflexions occur. Satellite imageries such as IKONOS, Quickbird, Worldview-1/2, SPOT PAN, XS, ASTER with 1.2-15m resolution are adequate for assessing impact of road on urban landscape research. Roads were thus sensitive to grain size of 15×15m² because most of the roads in the study area were 10-20m wide. High percent coverage of roads indicated high patch density of landscape. A major ecological impact of roads in process of urban land transformation was leading to habitat fragmentation.

5. Conclusion

The present research work adopted a combined method of landscape metrics analysis and sensitivity of metrics to varying grain size to analyze impact of road dynamics on landscape pattern Delhi, India. For this, degree of urbanisation and infrastructure developmental (roads) were considered focal factors. The research design helped to answer research objectives such as how changes of road patches alters urban landscape pattern and what is the degree of changes at varying grain size. The major findings include (i) landscape compositional diversity and degree of fragmentation is positively correlated to degree of urbanization both along rural-urban – rural gradient, (ii) road patch type has unique spatial signature as compared with other LULC types, which differ with varying grain size, (iii) different patch type have differential and distinguishable landscape pattern attributes along transect and across various grain resolution, and (iv) changes in pattern of road structures shows positive correlation to degree of urbanization and developmental activities. This study is a step in direction of better understanding of impacts of road on landscape pattern and processes both of which would tend to have severe ecological consequences. The study also substantiated that urban landscape is more heterogeneous in composition and are mostly fragmented.

Landscape metrics quantify pattern of landscape within designated landscape boundary and facilitates differential scenario based planning. Grain size is one important parameter in such analysis and provides insights to regional planning scales. Consequently, through the interpretation of these metrics and ecological significance of grain size an acute awareness of the landscape context and openness of landscape relative to phenomenon under consideration can be determined. The concept can be applied to identify indicators to mitigate negative effect of urbanization and sustainable LULC planning in urban landscapes.

References


